FORM 2

The Patent Act 1970

(39 of 1970)

&

The Patent Rules, 2003

COMPLETE SPECIFICATION

(See Section 10 and Rule 13)

TITLE OF THE INVENTION

SYSTEM FOR RIGIDISATION OF SPACECRAFTS USING KINEMATIC LINKAGE BASED DEPLOYABLE LEVER MECHANISM

NAME AND ADDRESS OF THE APPLICANT

INDIAN SPACE RESEARCH ORGANISATION,
DEPARTMENT OF SPACE, ANTARIKSH BHAVAN, NEW BEL ROAD BANGALORE - 560094, INDIA

NATIONALITY

A Government of India Organisation

The following specification particularly describes the invention and the manner in which it is to be performed:

TECHNICAL FIELD

[001] This invention relates to a docking mechanism employed in spacecrafts and more particularly related to a system for rigidisation of spacecrafts using kinematic linkage based deployable lever mechanism.

BACKGROUND OF INVENTION

[002] Space exploration has long been a frontier of human ingenuity, pushing the boundaries of technology and engineering to achieve ever more ambitious goals. Space missions encompass a wide range of endeavors aimed at exploring and utilizing space for scientific research, technological development, commercial activities and international collaboration. One of the key aspects contributing to the success of space missions is the ability to dock spacecrafts. Docking is a critical operation, which enables spacecrafts to join together in an orbit. Docking facilitates various purposes such as crew transfer, cargo exchange, formation flying and assembly of larger structures.

[003] Docking typically involves a two-step process: rendezvous and capture. Rendezvous involves maneuvering the ‘chaser’ spacecraft to match the target spacecraft’s position, velocity and orientation using onboard propulsion systems and guidance algorithms. Once in close proximity, the chaser spacecraft initiates the capture sequence to securely attach to the target spacecraft. Various docking mechanisms exist for this purpose, ranging from ‘soft’ capture methods involving docking rings and latches to ‘hard’ capture methods that create a rigid structural connection between the spacecrafts. After capture, the docking mechanisms may also establish power, data and fluid connections between the spacecrafts as needed. Advancements in spacecraft docking technology play a crucial role in enabling complex space missions, including space exploration, satellite servicing, space station operations and future crewed missions to the Moon, Mars and beyond.

[004] Conventional docking mechanisms, such as the International Berthing and Docking Mechanism (IBDM), serves as a standardized interface that enables the connection of different spacecrafts and modules. IBDM has served its purpose well for larger spacecraft and space stations. As illustrated in Fig **1**, the conventional docking mechanisms often consist of multiple motor drives, latches and pyrotechnic devices, resulting in a significant mass and complexity overhead. For example, the IBDM utilizes 24 motor drives and 12 pyrotechnics for individual latches, adding to the overall mass and complexity of the system. The reliance on numerous motor drives and pyrotechnic devices introduces potential points of failure, reducing overall system reliability. While redundancy measures are typically implemented to mitigate this risk, they further increase mass and complexity.

[005] Since conventional docking mechanisms are optimized for larger spacecrafts, they may not be well-suited for smaller, low-inertia spacecrafts. Adapting these mechanisms to smaller missions often requires significant modifications, resulting in additional technical challenges and costs. Moreover, the mass and complexity of conventional docking mechanisms contribute to higher launch costs, particularly for small satellite missions where payload mass is a critical factor. Reducing the mass and complexity of docking systems can help mitigate these costs and improve overall mission affordability.

[006] Additionally, the design of conventional docking mechanisms needs be optimized to avoid interference with other spacecraft components during docking and undocking maneuvers. Ensuring compatibility and minimizing interference becomes increasingly challenging as the size of the spacecraft and mission complexities vary. As space agencies and private organizations increasingly turn their attention to smaller spacecraft and missions, there is a growing need for docking mechanisms that are more compact, efficient and adaptable to varying mission requirements.

[007] Therefore, there is a need for a unique solution that addresses the challenges of the conventional docking mechanisms by prioritizing mass optimization, simplicity, reliability and adaptability.

[008] The above-mentioned shortcomings, disadvantages and problems are addressed herein, which will be understood by reading and studying the following specification.

OBJECT OF INVENTION

[009] The principal object of the embodiments herein is to provide a deployable lever mechanism for smaller spacecrafts.

[0010] Another objective of the present invention is to provide a deployable lever mechanism for reducing the overall mass and complexity of the system.

[0011] Yet another objective of the present invention is to provide a deployable lever mechanism for increasing the reliability of the system.

[0012] Still another objective of the present invention is to provide a deployable lever mechanism for increasing the adaptability to low inertia spacecrafts.

[0013] Yet another objective of the present invention is to provide a deployable lever mechanism for reducing costs thereby improving the overall mission affordability.

[0014] Still another objective of the present invention is to provide a deployable lever mechanism for avoiding interference with other spacecraft components.

SUMMARY

[0015] Accordingly, the embodiments herein provide a deployable lever mechanism for rigidisation of at least two spacecrafts during docking in a spacecraft docking system. The deployable lever mechanism includes a primary lever assembly consisting of a primary link and a secondary link connected together with a revolute joint. The primary lever assembly is configured for joining two spacecraft and applying necessary preload to achieve composite stiffness for controlling two spacecraft together as a composite body. The primary link is connected to a mechanism housing using a fork end bracket and the secondary link is rigidly connected with the primary link using a spur sector pinion and gear pair.

[0016] According to an embodiment, the spur gear pair meshes together to transfer true motion from the primary link to the secondary link during movement. In yet another embodiment, the deployable primary lever assembly applies requisite preload during rigidisation using the secondary link at a predetermined interface through a pre-tensioned wire rope connecting all the plurality of deployable primary levers together.

[0017] According to still another embodiment, the primary link rotates by a predefined angle, the secondary link rotates by a different angle, thereby ensuring a gear ratio for effective preload application. Still in yet another embodiment, the specified gear ratio is configured to avoid interference of primary levers on a target with chaser docking mechanism during initial docking phase by folding the secondary link below the separation plane.

[0018] Further, in accordance to an embodiment, a torsion spring assembly is used to keep the secondary lever inactive in a preloaded condition during launch to prevent fluttering due to launch vibrations. Additionally, in accordance to yet another embodiment, the motion in the levers is transferred

through a plurality of pulleys and rope to ensure predefined stiffness in the system without deformation.

[0019] Additionally, in accordance to an embodiment, the deployable lever mechanism is having a modular design to reduce dependency on other subsystems during assembly and testing. Additionally, in accordance to an embodiment, the deployable lever mechanism includes telemetry indication using contact switches for critical positions and on-orbit preload monitoring using strain gauges.

[0020] Further, in accordance to an embodiment, the spacecraft docking system is configured to rigidize target interface ring with a chaser interface ring during final docking phase. Additionally, according to an embodiment, the spacecraft docking system is configured to avoid interference of primary levers on the target with chaser docking mechanism during initial docking phase byfolding the secondary link on a target below separation plane during launch.

[0021] According to an embodiment, the spacecraft docking system provides a self-hold down feature through a single wire loop connected to a drive pulley using a non-back drivable actuator. Further, in accordance to an embodiment, the spacecraft docking system provides a self-hold down feature through a single wire loop connected to a drive pulley using a non-back drivable actuator.

[0022] According to yet another embodiment, the space docking system is configured with redundancy by providing a similar configuration of the docking mechanism in both chaser and target spacecraft.

[0023] These and other aspects of the embodiments herein will be better appreciated and understood when considered in conjunction with the following description and the accompanying drawings. It should be

understood, however, that the following descriptions, while indicating preferred embodiments and numerous specific details thereof, are given by way of illustration and not of limitation. Many changes and modifications may be made within the scope of the embodiments herein without departing from the spirit thereof, and the embodiments herein include all such modifications.

BRIEF DESCRIPTION OF THE DRAWINGS

[0024] Embodiments herein are illustrated in the accompanying drawings, throughout which like reference letters indicate corresponding parts in the various figures. The example embodiments herein will be better understood from the following description with reference to the drawings, in which:

[0025] Figure **1** illustrates a schematic of International Berthing and Docking Mechanism.

[0026] Figure **2** illustrates satellites in close proximity & satellites in docked configuration.

[0027] Figure **3** illustrates deployable primary lever mechanism, in accordance with an embodiment of the present invention.

[0028] Figure **4** illustrates schematic of rigidisation mechanism, in accordance with an embodiment of the present invention.

[0029] Figure **5** illustrates avoiding of interference of primary levers on target with chaser docking mechanism, in accordance with an embodiment of the present invention.

[0030] Figure **6** illustrates deployable primary lever during launch, in accordance with an embodiment of the present invention.

[0031] Figure **7** illustrates deployable primary lever mechanism in launch and rigidised configuration, in accordance with an embodiment of the present invention.

[0032] Figure **8** illustrates schematic of compound lever mechanism, in accordance with an embodiment of the present invention.

[0033] Figure **9** illustrates other views of primary lever mechanism, in accordance with an embodiment of the present invention.

[0034] Figure **10** illustrates different configurations of primary lever mechanism, in accordance with an embodiment of the present invention.

[0035] Figure **11** illustrates overall configurations of primary lever mechanism, in accordance with an embodiment of the present invention.

[0036] Figure **12** illustrates switch locations for various conditions on primary lever mechanism, in accordance with an embodiment of the present invention.

[0037] Figure **13** illustrates deployable lever mechanism hardware realized, in accordance with an embodiment of the present invention.

DETAILED DESCRIPTION OF THE INVENTION

[0038] The embodiments herein and the various features and advantageous details thereof are explained more fully with reference to the non-limiting embodiments and detailed in the following description. Descriptions of well-known components and processing techniques are omitted so as not to unnecessarily obscure the embodiments herein. The examples used herein are intended merely to facilitate an understanding of ways in which the embodiments herein may be practiced and to further enable those of skill in the art to practice the embodiments herein. Accordingly, the examples should not be construed as limiting the scope of the embodiments herein.

[0039] Some embodiments of this disclosure, illustrating all its features, will now be discussed in detail. The words "enabling", "establishing", and other forms thereof, are intended to be open ended in that an item or items following any one of these words is not meant to be an exhaustive listing of such item or items or meant to be limited to only the listed item or items. It must also be noted that as used herein and in the appended claims, the singular forms "a," "an," and "the" include plural references unless the context clearly dictates otherwise. The terms “comprises,” “comprising,” “has,” “having,” “includes” and/or “including” as used herein, specify the presence of stated features, elements, and/or components and the like, but do not preclude the presence or addition of one or more other features, elements, components and/or combinations thereof. The term “an embodiment” is to be read as “at least one embodiment.” The term “another embodiment” is to be read as “at least one other embodiment.” Although any system and methods similar or equivalent to those described herein can be used in the practice or testing of embodiments of the present disclosure, the exemplary system and methods are now described.

[0040] The disclosed embodiments are merely examples of the disclosure, which may be embodied in various forms. Various modifications to the embodiment will be readily apparent to those skilled in the art and the generic principles herein may be applied to other embodiments. However, one of ordinary skill in the art will readily recognize that the present disclosure is not intended to be limited to the embodiments described but is to be accorded the widest scope consistent with the principles and features described herein.

[0041] There is a need for a unique solution that addresses the challenges of the conventional docking mechanisms by prioritizing mass optimization, simplicity, reliability and adaptability.

[0042] Figure **2** illustrates satellites in close proximity & satellites in docked configuration. Figure **3** illustrates deployable primary lever mechanism. Figure **4** illustrates schematic of rigidisation mechanism. Figure **5** illustrates avoiding of interference of primary levers on target with chaser docking mechanism. Figure **6** illustrates deployable primary lever during launch, in accordance with an embodiment of the present invention.

[0043] In the present invention, a deployable lever mechanism for rigidisation of at least two spacecrafts during docking in a spacecraft docking system is disclosed. The deployable lever mechanism includes a primary lever assembly consisting of a primary link and a secondary link connected together with a revolute joint, wherein the primary lever assembly is configured for joining two spacecraft and applying necessary preload to achieve composite stiffness for controlling two spacecraft together as a composite body. The primary link is connected to a mechanism housing using a fork end bracket and the secondary link is rigidly connected with the primary link using a spur sector pinion and gear pair.

[0044] In one implementation, the spur gear pair meshes together to transfer true motion from the primary link to the secondary link during movement. In yet another implementation, the deployable primary lever assembly applies requisite preload during rigidisation using the secondary link at a predetermined interface through a pre-tensioned wire rope connecting all the plurality of deployable primary levers together.

[0045] In yet another implementation, the primary link rotates by a predefined angle, the secondary link rotates by a different angle, thereby ensuring a gear ratio for effective preload application. Further, in yet another implementation, the specified gear ratio is configured to avoid interference of primary levers on a target with chaser docking mechanism during initial docking phase by folding the secondary link below the separation plane.

[0046] In one implementation, a torsion spring assembly used to keep the secondary lever inactive in a preloaded condition during launch to prevent fluttering due to launch vibrations. Additionally, in yet another implementation, the motion in the levers is transferred through a plurality of pulleys and rope to ensure predefined stiffness in the system without deformation.

[0047] Further, in one implementation, the deployable lever mechanism is having a modular design to reduce dependency on other subsystems during assembly and testing. In yet another implementation, the deployable lever mechanism includes telemetry indication using contact switches for critical positions and on-orbit preload monitoring using strain gauges.

[0048] Additionally, in one implementation, the spacecraft docking system is configured to rigidize target interface ring with a chaser interface ring during final docking phase. In yet another implementation, the spacecraft docking system is configured to avoid interference of primary levers on the target with chaser docking mechanism during initial docking phase byfolding the secondary link on a target below separation plane during launch.

[0049] In yet another implementation, the spacecraft docking system provides a self-hold down feature through a single wire loop connected to a drive pulley using a non-back drivable actuator. Further, in one implementation, the spacecraft docking system provides a self-hold down feature through a single wire loop connected to a drive pulley using a non-back drivable actuator.

[0050] Additionally, in another implementation, the space docking system is configured with redundancy by providing a similar configuration of the docking mechanism in both chaser and target spacecraft.

[0051] In the present invention, the configuration of the docking mechanism serves dual purpose of avoiding interference of primary levers on target with chaser docking mechanism during initial docking phase by ingeniously folding the secondary link on target below the separation plane and applying the necessary preload for launch. Further, it facilitates for application of desired rigidisation preload at the target interface using chaser primary levers during final docking phase. In addition, Secondary lever is kept inactive in preloaded condition during launch by ingenious usage of torsion spring assembly to prevent chattering due to launch vibrations and the preload to sustain launch loads is applied using interface on primary link. This minimizes the actuator torque requirements and subsequently saves mass.

[0052] In the present invention, deployable primary levers apply the necessary preload at a suitable interface through tensioned SS wire rope connecting all the three levers together. The motion in the levers is transferred through pulleys and wire rope. The use of single cable minimizes the no. of motors to one. Mechanism is modular in nature which reduces dependability on other subsystems during assembly and testing. Additionally, mechanism has provision for a contact switch-based telemetry indication for launch, release and rigidised position. The deployable primary levers also have a provision for on orbit preload monitoring using strain gauges. Levers are configured to avoid any interference between other mechanical elements during docking. This mechanism avoids a separate hold down mechanism to sustain launch loads by usage of self-locking property of worm and worm gears which thereby reduces complexity and lowers the degree of dependence on the available electrical resources.

[0053] According to an embodiment of the present invention, a deployable primary lever mechanism is disclosed comprising two kinematic links, namely, a primary link and a secondary link, which are interconnected

via a revolute joint. The deployable primary lever assembly further comprises a primary link attached to a mechanism housing using a fork end bracket, with the secondary link rigidly connected to the primary link using a spur sector pinion and gear pair. The primary lever is responsible for applying the requisite preload at a suitable interface on the target interface ring for both launch and rigidization conditions. A spur gear pair facilitates the transmission of motion from the primary link to the secondary link during movement. Operationally, when a stepper motor is instructed to rotate by a desired number of steps, a pulley rotates, causing the winding of a wire rope around it. To achieve the launch condition preload, the deployable primary lever closest to the motor initially rotates by 26^0 from the released position, subsequently transmitting this motion to the remaining two sets of levers, thereby generating the clamping force necessary to withstand launch loads. The lever is pivotally mounted on a shaft with appropriate clearances to enable free rotation. Similarly, during rigidization conditions, the deployable primary lever is actuated by 16^0 from the release position.

[0054] In the present invention, the lever is designed to offer leverage within a range of 3 to 5.9, thereby assisting in reducing the tension required in the wire loop by a corresponding ratio of the total out-of-plane launch load acting on the system. As illustrated in figure **7**, interfaces are configured to enable a single lever to operate under both conditions without interference with other elements. As illustrated in figures **8** and **9**, the deployable lever assembly includes a secondary link rigidly connected to a sector pinion and gear, with the spur gear-pinion pair having a gear ratio of 4.5:1, facilitating the rotation of the secondary link with respect to the primary lever during movement. In the present embodiment, as the primary lever rotates by 26^0, the secondary link rotates by 117^0 and the same is illustrated in figure **10**. A torsion spring, also referred to as a retention spring, mounted on the hinge of the lever aids in the release of the lever during

undocking. Tension in the loop is monitored using strain gauges mounted on tension monitoring brackets and the levers, with tension adjustments achieved by overdriving the motor. The overall configuration of the primary lever mechanism is illustrated in figure **11**. The primary lever mechanism, along with contact switches for indicating launch, release, and rigidized conditions, is depicted in the figure **12**. Hardware images of deployable lever mechanism is illustrated in figure **13**.

[0055] It must be understood that reference of any specific application in current disclosure, such as the space craft application, is merely provided for the ease of explanation, and should not be construed as a limiting factor for application of the methodologies described herein. Therefore, it is fairly possible for a person skilled in the art to utilize the details provided in current disclosure for any similar application.

[0056] Any combination of the above features and functionalities may be used in accordance with one or more embodiments. In the foregoing specification, embodiments have been described with reference to numerous specific details that may vary from implementation to implementation. The specification and drawings are, accordingly, to be regarded in an illustrative rather than a restrictive sense. The sole and exclusive indicator of the scope of the invention, and what is intended by the applicants to be the scope of the invention, is the literal and equivalent scope of the set as claimed in claims that issue from this application, in the specific form in which such claims issue, including any subsequent correction.

[0057] In the above description, for purposes of explanation, numerous specific details are set forth in order to provide a thorough understanding of the present systems and methods. It will be apparent the systems and methods may be practiced without these specific details. Reference in the specification to “an example” or similar language means that a particular feature, structure, or characteristic described in connection

with that example is included as described, but may not be included in other examples.

[0058] The foregoing description of the specific embodiments will so fully reveal the general nature of the embodiments herein that others can, by applying current knowledge, readily configure and/or adapt for various applications such specific embodiments without departing from the generic concept, and, therefore, such adaptations and modifications should and are intended to be comprehended within the meaning and range of equivalents of the disclosed embodiments. It is to be understood that the phraseology or terminology employed herein is for the purpose of description and not of limitation. Therefore, while the embodiments herein have been described in terms of preferred embodiments, those skilled in the art will recognize that the embodiments herein can be practiced with modification within the spirit and scope of the embodiments as described herein.

I/We Claim:

1. A deployable lever mechanism for rigidisation of at least two spacecrafts during docking in a spacecraft docking system, the deployable lever mechanism comprising:

   a primary lever assembly consisting of a primary link and a secondary link connected together with a revolute joint, wherein the primary lever assembly is configured for joining two spacecraft and applying necessary preload to achieve composite stiffness for controlling two spacecraft together as a composite / single body; and

   the primary link is connected to a mechanism housing using a fork end bracket; and the secondary link is rigidly connected with the primary link using a spur sector pinion and gear pair.

2. The deployable lever mechanism as claimed in claim 1, wherein the spur gear pair meshes together to transfer true motion from the primary link to the secondary link during movement.

3. The deployable lever mechanism as claimed in claim 1, wherein the deployable primary lever assembly applies requisite preload during rigidisation using the secondary link at a predetermined interface through a pre-tensioned wire rope connecting all the plurality of deployable primary levers together.

4. The deployable lever mechanism as claimed in claim 3, wherein as the primary link rotates by a predefined angle, the secondary link rotates by a different angle, thereby ensuring a gear ratio for effective preload application.

5. The deployable lever mechanism as claimed in claim 4, wherein the specified gear ratio is configured to avoid interference of primary levers on a target with chaser docking mechanism during initial docking phase by folding the secondary link below the separation plane.

6. The deployable lever mechanism as claimed in claim 1, further comprising a torsion spring assembly used to keep the secondary lever inactive in a preloaded condition during launch to prevent fluttering due to launch vibrations.

7. The deployable lever mechanism as claimed in claim 1, wherein the motion in the levers is transferred through a plurality of pulleys and rope to ensure predefined stiffness in the system without deformation.

8. The deployable lever mechanism as claimed in claim 1, wherein the deployable lever mechanism is having a modular design to reduce dependency on other subsystems during assembly and testing.

9. The deployable lever mechanism as claimed in claim 1, wherein the deployable lever mechanism includes telemetry indication using contact switches for critical positions and on-orbit preload monitoring using strain gauges.

10. The deployable lever mechanism as claimed in claim 1, wherein the spacecraft docking system is configured to rigidize target interface ring with a chaser interface ring during final docking phase.

11. The deployable lever mechanism as claimed in claim 1, wherein the spacecraft docking system is configured to avoid interference of primary levers on the target with chaser docking mechanism during

initial docking phase byfolding the secondary link on a target below separation plane during launch.

12. The deployable lever mechanism as claimed in claim 1, wherein the spacecraft docking system provides a self-hold down feature through a single wire loop connected to a drive pulley using a non-back drivable actuator.

13. The deployable lever mechanism as claimed in claim 1, wherein the space docking system is configured with redundancy by providing a similar configuration of the docking mechanism in both chaser and target spacecraft.

Dated this on 08th day of February 2024

Signature
-Digitally Signed-
SANTOSH VIKRAM SINGH
IN/PA:414
Agent for the Applicant

ABSTRACT

SYSTEM FOR RIGIDISATION OF SPACECRAFTS USING KINEMATIC LINKAGE BASED DEPLOYABLE LEVER MECHANISM

The embodiments herein provide a method and a deployable lever mechanism for rigidisation of at least two spacecrafts during docking in a spacecraft docking system. The deployable lever mechanism includes a primary lever assembly consisting of a primary link and a secondary link connected together with a revolute joint. The primary lever assembly is configured for joining two spacecraft and applying necessary preload to achieve composite stiffness for controlling two spacecraft together as a composite body. Further, the primary link is connected to a mechanism housing using a fork end bracket and the secondary link is rigidly connected with the primary link using a spur sector pinion and gear pair.

FIG.10